GULLY DEVELOPMENT IN AGRICULTURAL FIELDS: INSIGHTS FROM CATCHMENT SCALE ANALYSIS

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1. Introduction

In recent years, soil erosion has become an important topic in the local, national and international decisions maker's agenda (Van Rompaey et al. 2003). Specifically, soil erosion by water is a major environmental problem (Fernandez et al. 2003), that worsens through intensive agricultural activity, soil degradation and heavy rainfall events (Amore et al. 2004). Gully erosion is one of the most effective mechanisms that cause damage to agricultural areas all over the world (Casalí et al. 2006), especially in Mediterranean and semiarid environments (Poesen et al. 2003). The need to estimate soil loss potential due to gully erosion, in large agricultural areas, is therefore well recognized (Amore et al. 2004). However, reliable estimations of gully development require understanding of the factors that influence gully development including physical conditions and human activities (Valcárcel et al. 2003). The effect of physical factors on gully head position and gully development is widely studied (Valentin et al. 2005) while most of these studies have used empirical approaches mainly in the plot/local scale. However, despite the fact that human activities have become the key contributing factor to regional soil erosion, still, most current prediction models have been unable to discern this effect on gully development (Ni and Li 2003).

Our *aim* is to study the combined effect of human-induced activity and the physical environmental conditions on gully development in a small agricultural catchment in Northern Israel. More specifically we address the following objectives: 1) to test inter-correlation between physical factors and human activities; 2) to quantify effects of physical and human factors on gully development; 3) to use GIS-based model to predict gully development; 4) to test our model against existing topographic threshold model.

2. Study area

The study area is a sub-catchment in the Harod River Basin, located in Northern Israel (Fig. 1). Catchment area is 13 km^2 and the slope range of cultivated fields is 0-28°. Agricultural land-uses are mainly field crops and orchards. The climate is of a transition zone between Mediterranean and semi arid with annual rainfall depth of 450 mm and potential evaporation is 170 cm. The soils are alluvials (vertisols) in the center of the study area and colluviums in the margins. Topsoils texture is generally clay. Organic matter ranges between 4.8 and 7.6%.

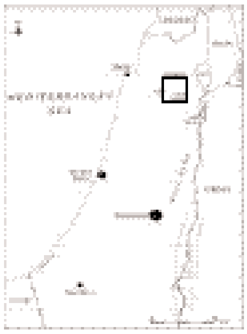

Fig. 1. Location of the study area.

3. Methods

3.1. GIS database design

Five physical and human activity factors were selected.

Physical environment: A contour-based digital elevation model was extracted from a topographic map of the Survey of Israel with 5-meters interval. Three layers were calculated from the DEM: slope, aspect and upslope contributing area. Saturated hydraulic conductivity was measured in a field survey: 72 Samples were analyzed for particle size distribution using hydrometer method and texture data were calculated. Organic matter for each soil sample was determined by LOI method. Texture data and organic matter placed into a SPAW Hydrology program, to determined soil water characteristics. The saturated hydraulic conductivity data was interpolated as raster layer based on the study area soil formation map.

Human activities: Tillage directions were coded from January 2003-air photo. To express their effect on erosion potential, we used Ganskopp cosine cost function (Ganskopp et al. 2000):

$$\cos t = \text{slope}^{f} \qquad (1)$$

$$f = \cos^2 a \qquad (2)$$

where *f*- is the effective friction, *a*- is the angle between the aspect and tillage direction. The unpaved roads were digitized from 2003 air photo. Tripled rings buffer of 30, 60 and 90 meters were produced down-slope to the unpaved roads.

3.2. Model approach

We used fuzzy logic (Openshaw & Openshaw 1997) to model vulnerability to gully development. For each variable, membership function (MF) was selected to express its effect on vulnerability (Table 1).

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Table 1. The variable and the matching memberships' functions and relevant weights for the linear joint membership function. Where P_{min} and P_{max} are the minimum and maximun threshold values and x is the value at the i,j location.

Attribute	Id	MF type	MF	Weight
Saturated Hydraulic Conductivity	MF1	Sigmoidal	$\cos^2\left(\left(\frac{x-P_{min}}{P_{max}-P_{min}}\right)\bullet\left(\frac{\pi}{2}\right)\right)$	0.33
Slope	MF2	Sigmoidal	$1-\cos^2\left(\left(\frac{x-P_{min}}{P_{max}-P_{min}}\right)\bullet\left(\frac{\pi}{2}\right)\right)$	0.34
Flow Accumulation	MF3	Linear	$1-\frac{P_{max}-x}{P_{max}-P_{min}}$	0.33
Tillage direction	MF4	Sigmoidal	$1-\cos^2\left(\left(\frac{x-P_{min}}{P_{max}-P_{min}}\right)\bullet\left(\frac{\pi}{2}\right)\right)$	0.5
Roads	MF5	Categorial		0.5

To produce a vulnerability map, for each of the factors (physical environment, human activities, and combined model), we used the convex combination operation (Svoray et al. 2004). Equation (3) shows predictions for the combined effect of the two factors (values between 0-1):

$$JMF = MF1\cdot 0.2 + MF2\cdot 0.2 + MF3\cdot 0.2 + MF4\cdot 0.2 + MF5\cdot 0.2 \quad (3)$$

3.3. Model validation

Visual interpretations of air photos, field and laboratory measurements were used to validate and test the models.

Air-photos were interpreted to identify gullies and gully heads from 2003 and 2006 and maps were digitized. Buffers around the gullies and the gully heads were operated and local slope, contributing area and length were calculated. Depth and width were measured in the field for a sample of 21 gullies.

4. Results

Fig. 2a shows that in the physical model even areas of low scores are still covered by large number of gullies. The model that reflects the effect of human activities alone (fig. 2b) can not fully explain the phenomena either. However, the combined model (fig. 2c) could produce better predictions of both initial points and gully development.

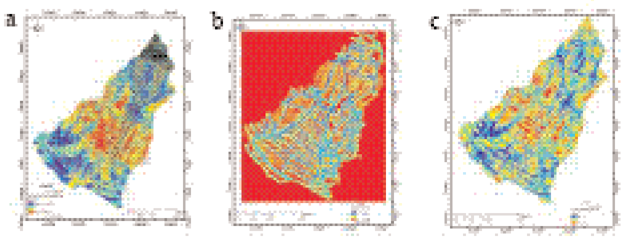

Fig. 2. The sub-models (a- physical; b- human; c- combined). Results and the existing gullies in the study area, that were generated from 2003 air-photo.

Visual interpretation of 76 gully heads was used to test the models by comparing their fuzzy membership scores (fig. 3). The results show that by adding the human activity to the physical properties, higher percentage of gully heads, can be explained.

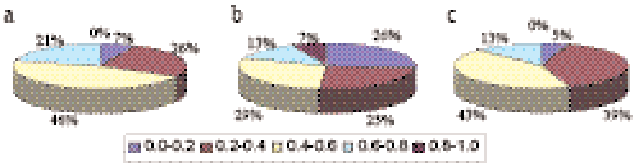

Fig. 3. Frequencies of initial points that were identified in the area according to each sub-models (a- physical; b- human; c- combined). The groups are following the fuzzy membership scores: 1-highest risk; 0-the lowest.

5. Conclusion

The integration of the physical properties and the human activity in the catchment explained the observed gullies in the area. By getting accurate and updated results, we will be able to produce prediction maps for gully development risks and to quantify the effects of each human and physical factor.

Acknowledgments: This work was financially supported by The Israeli Soil Sciences Advisory Board.

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